

Secondary Reconstructive Procedures in Obstetrical Brachial Plexus Palsy: Forearm, Wrist, and Hand Deformities

Panayotis N. Soucacos, M.D., F.A.C.S.,¹ Marios D. Vekris, M.D.,²
John Kostas, M.D.,³ and Elizabeth O. Johnson, Ph.D.⁴

ABSTRACT

Obstetrical brachial plexus paralysis (OBPP) is a complex, multifaceted disorder with potentially disabling sequelae. Although the shoulder is the most frequently affected joint, the forearm, wrist, and hand may also display disabling deformities. In sequelae involving the forearm, the most frequent deformity is supination contractures followed by pronation contractures. Treatment of OBPP has recently focused on early microsurgical repair; nonetheless, palliative surgery still plays a critical role in the overall reconstructive planning in order to diminish the sequelae of OBPP and improve function of the upper extremity. The preferred palliative surgical procedures for the forearm and hand include flexor or extensor tendon transfers, free muscle transfers, opponensplasty, and bone fusion. The most commonly restored functions are elbow flexion and extension, finger flexion and extension, and, in some cases, shoulder abduction and intrinsic substitution.

KEYWORDS: Obstetrical paralysis, supination deformity, ulnar deviation, wrist drop

Obstetrical brachial plexus paralysis (OBPP) is a complex, multifaceted disorder with potentially disabling sequelae. OBPP occurs as a result of an extreme lateral traction of the infant's head away from the shoulder during the last phase of delivery, resulting in variable traction or stretch neural lesion. Although many children with OBPP progress to useful neurological recovery, it is essential for the surgeon to encourage this potential function further by earlier detection and appropriate treatment.

A multidisciplinary approach that includes various specialties as well as a carefully timed integrated approach to treatment that includes conservative, primary, and secondary treatment modalities is essential to achieve optimal results. Although the global

strategy in the treatment of OBPP has recently focused on early microsurgical repair, as it leads to substantial functional improvement of upper extremity function, palliative surgery still plays a critical role in the overall reconstructive planning. Today, it is clear that secondary reconstructive procedures must be kept in mind even during the initial microsurgical plexus reconstruction to effectively improve the overall functional results.

CLASSIFICATION OF OBSTETRICAL PARALYSIS

OBPP can be classified according to its anatomical features or its clinical course and severity. Anatomical

Obstetrical Brachial Plexus Paralysis, Part 2; Editor in Chief, Saleh M. Shenaq, M.D.; Guest Editors, Julia K. Terzis, M.D., Ph.D., and Saleh M. Shenaq, M.D. *Seminars in Plastic Surgery*, Volume 19, Number 1, 2005. Address for correspondence and reprint requests: Panayotis N. Soucacos, M.D., F.A.C.S., Department of Orthopaedic Surgery, University of Athens, School of Medicine, "K.A.T." Accident Hospital, 2 Nikis Street, 145 61 Kifisia, Athens, Greece. ¹Department of Orthopaedic Surgery, University of Athens, School of Medicine, Athens, Greece; ²Orthopaedic Department, Ioannina University Medical School, Ioannina, Greece; ³Microsurgical Unit, Eastern Virginia Medical School, Norfolk, Virginia; ⁴Department of Anatomy, Ioannina University Medical School, Ioannina, Greece. Copyright © 2005 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001 USA. Tel: +1(212) 584-4662. 1535-2188,p;2005,19,01,096,102,ftx,en;sps00157x.



Figure 1 Preoperative view of an 8-month-old infant with total plexus palsy. The infant shows typical internal rotation of the humerus, supination of the forearm, and ulnar deviation of the wrist and hand.

classification includes four categories: upper plexus palsy (Erb palsy), which involves C5, C6, and sometimes C7¹; intermediate plexus palsy, which involves C7 and sometimes C8 and T1²; lower plexus palsy (Klumpke palsy), which involves C8 and T1³; and total plexus palsy, which involves C5, C6, C7, C8, and sometimes T1.⁴ Total plexus palsy is usually the cause of deformities of the forearm and hand (Fig. 1).

According to the overall severity of the lesion, five clinical types have been identified according to Narakas.⁵ Type I indicates a relatively mild palsy, and recovery is usually complete or almost complete by 1–8 weeks. Type II is more unpredictable early on. In these cases, the elbow usually shows good function, but the shoulder does not. In addition, wrist and finger extension may also not recover in some patients, requiring tendon transfers. Type III may present a temporary Horner syndrome and appear complete. These cases involve the upper trunk and include avulsion of C7, as well as stretching of the lower trunk. Type IV is characterized by a persisting Horner syndrome, with avulsion injury of C8 and T1. Type IV patients may show recovery of C5 and C6 function. Type V is defined by severe injury of all of the roots of the brachial plexus. These patients present with paralysis of the serratus anterior, levator scapulae, and rhomboids, with a permanent Horner's sign.

NATURAL HISTORY AND INDICATIONS

Knowledge of the natural history and the potential sequelae of obstetrical paralysis is critical for determining the best form of management. Although several OBPP patients do recover with relatively minor, if any, residual functional deficits, there are several infants who do not regain satisfactory function of their upper limb. These infants subsequently develop bony deformities, joint contractures, and related functional limitations. In general, about half of the OBPP patients have identifiable impairment of hand function at ~15 months of age.⁶ To avoid permanent sequelae, many surgeons are proposing the necessity for early surgical intervention.^{4,7–9}

Today, the most widely used set of guidelines for early intervention are those proposed by Gilbert and Tassin.¹⁰ According to Gilbert and Tassin, functional prognosis is poor, and surgical repair of the plexus is warranted with the following: total palsy with a flail arm and Horner's syndrome after 1 month; no signs of recovery by the third month in patients with complete C5–C6 palsy after breech delivery; and absent biceps function by the third month in infants with C5–C6 palsies.

SEQUELAE OF OBSTETRICAL BRACHIAL PLEXUS PALSY

The sequelae of obstetrical palsy are related to the initial lesion of the brachial plexus, as well as the lesions of the osteoarticular system at the level of the proximal humerus and damage to the deep periarticular muscles of the shoulder.¹¹ Neuropraxia, axonotmesis, and root avulsions are associated with varying lesions to the sensory, motor, and autonomic nerve fibers of the brachial plexus.

The principle clinical characteristic of the primary lower arm sequelae are the result of an initial total lesion of the plexus (C5–T1). Depending on the condition of the upper, middle, and lower plexus, partial recovery or complete paralysis of certain muscles can be observed, with major deformities being observed at the level of the forearm, wrist, and hand. In a relatively large series with 368 sequelae cases, Zancolli indicated that the typical clinical picture includes internal rotation contracture of the shoulder (72%), flexion contracture of the elbow (62%), supination contracture of the forearm (69%), ulnar deviation of the wrist (27%), and varying types of finger paralysis.¹¹

Although the shoulder is by far the most frequently affected joint in OBPP, the forearm, wrist, and hand also frequently display disabling deformities. Despite this, forearm and hand reconstruction in OBPP has been discussed in relatively few papers.^{12–18} In sequelae involving the forearm, the most frequent deformity is supination contractures (69%).¹¹ Pronation contractures are observed in ~28% of the cases.

Overall, the most frequent sequelae deformities in the forearm and hand in OBPP patients include forearm supination contracture; forearm pronation contracture (less frequent than supination contractures); weak or absent wrist, metacarpophalangeal (MP) joint or interphalangeal (IP) joint extension; weak or absent flexion of digits; ulnar deviation of the wrist; thumb instability; and sensory disturbance, particularly of the two ulnar digits

SECONDARY RECONSTRUCTIVE PROCEDURES

Palliative surgery in brachial plexus palsy consists of an ensemble of secondary procedures that are used to diminish the sequelae of OBPP and improve function of the upper extremity. Such procedures consist of muscle-tendon transfers, tenodeses, capsulodesis, or arthrodeses. For secondary reconstructive procedures to effectively enhance overall function, the surgeon must be aware of the natural history of OBPP and the evolution of the particular patient, as well as the particular functional deficits presented by the patient. (This is essential because it is function that is reestablished, and not reanimation of paralyzed muscles). In addition, the surgeon must evaluate and verify the passive mobility of the joints, as well as their stability. The reconstructive possibilities available to the surgeon are dependent on the number of available active muscles and the condition of the entire limb. Joint stiffness, contractures, deformities, and associated skin, vessel, and bone problems must be considered in treatment planning. A general rule of thumb is that all contractures should be treated before surgical reconstruction of the paralysis.

Various procedures are performed for correction of forearm and hand deformities in OBPP. The preferred palliative surgical procedures to correct deformities or restore function include flexor or extensor tendon transfers, free muscle transfers, opponensplasty, and bone fusion. Secondary procedures such as muscle transfers and wrist fusion are necessary to improve function, especially in late cases in which the muscle targets have atrophied. Pedicled muscle or tendon transfers^{14,19-21} are used to enhance the functionality of the paretic arm. Advances in microsurgery began the era of free functional muscle transfer for brachial plexus paralysis management.^{22,23} The transferred free muscles are neurotized either by previously banked nerve grafts or directly from local motor donors (i.e., intercostal nerves). The most commonly restored functions are elbow flexion and extension, finger flexion, and extension, and in some cases, shoulder abduction and intrinsic substitution. Latissimus dorsi and rectus femoris transfer are good candidates for elbow flexion restoration. For hand reanimation, gracilis and rectus femoris can be used.²⁴ Some surgeons prefer to restore two functions with one

muscle transfer (i.e., elbow flexion and finger flexion or elbow extension and finger extension).^{25,26}

The surgical procedures selected depend on the pathology of the involved soft tissues and joints and the overall muscular condition. In general, a severe shoulder deformity should be corrected before any surgical procedure is attempted on the forearm. However, mild or moderate flexion contractures of the elbow do not contraindicate forearm surgery. Supination deformities and dorsiflexion and ulnar deviation of the wrist can be corrected next. The final step is any surgical correction of the hand.

SUPINATION DEFORMITIES

One relatively frequent obstetrical palsy sequelae is forearm supination deformity, which is usually associated with ulnar deviation of the wrist and variable deficits in hand function. Forearm supination deformity is a progressive deformity, ultimately resulting in severe retraction of the interosseus membrane and subluxation or dislocation of the distal radio-ulnar joint, and in some cases, even dislocation of the proximal radial head.

Supination contractures are disabling functional deficits that result from the unrestricted action of the supinator muscles (biceps and supinator) in the presence of paralysis of pronators. Although supination contractures can be reduced passively in their initial stages, after ~2 years, the interosseous membrane also begins to contract, and the deformity becomes fixed. This ultimately leads to bony curvature of the forearm, particularly of the radius, along with dislocation and volar subluxation of the distal end of the ulna. Sometimes the radial head may also be subluxed or dislocated volarly. It has been proposed that supination contractures should be corrected before the deformity becomes fixed.¹⁴

Forearm supination and deformity of the wrist (dorsiflexion and ulnar deviation) are often associated with weakness or paralysis of the digits and thumb, particularly of their intrinsic muscles. As a result of contracture of the collateral ligaments, the metacarpophalangeal joints of the fingers are stiff in extension. In addition, the thumb is often paralyzed and drawn in adduction. Because of the imbalance between the paralytic triceps and active biceps, the elbow is frequently in a flexion contracture.

The indications for surgical management of supination deformities include an evaluation of the condition of the interosseous membrane (whether it is flexible or retracted), the distal radio-ulnar joint, and the functional status of the triceps. The surgeon must also take into account deformities of the elbow or shoulder and the function of the hand. A moderate flexion contracture of the elbow does not contraindicate forearm surgery, although if a shoulder deformity is present, it should be corrected first. Reconstruction of the hand should follow

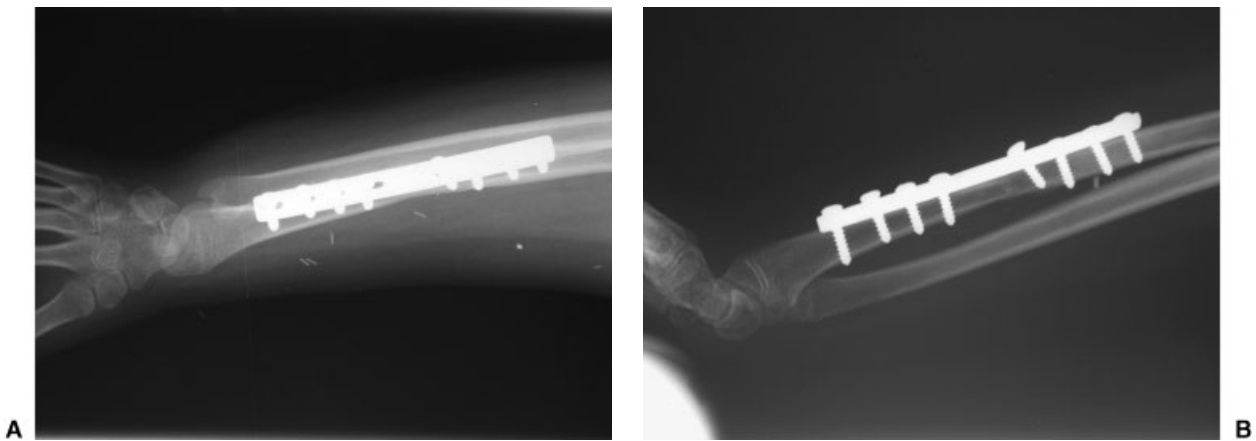


Figure 2 (A) Anteroposterior (AP) and (B) lateral radial osteotomy performed at the junction of the distal third of the radius in a 15-year-old boy to correct supination deformity of the forearm secondary to pronator muscle paralysis.

correction of supination deformities and dorsiflexed and ulnarly deviated wrists.

According to Zancolli and Zancolli,¹⁴ surgical correction of supination contractures can be achieved by transferring the distal end of the biceps to a pronation position or, alternatively, transferring the flexor carpi ulnaris to the brachioradialis tendon. This entails the triceps being adequately functional and the interosseous membrane being longitudinally divided. However, re-routing the biceps tendon to restore active pronation, as proposed by Zancolli and Zancolli,¹⁴ has not had satisfactory results in other studies, particularly in cases with fixed deformities and contracted interosseous membrane (Heerlen).^{27,28} However, pronation osteotomy of the radius has been shown to provide promising functional improvement (Fig. 2).^{9,29}

Patients who also present with palmar subluxation or dislocation of the distal radial head should be managed with release of the interosseous membrane and fusion of the distal end of the radius and ulna in a neutral rotation of the forearm. Fixation should be placed proximal to the radial growth plate if the distal radial-ulnar fusion is performed before completion of growth.

ULNAR DEVIATION OF THE WRIST

Frequently supination contractures are associated with flexible ulnar deviation of the wrist (27% in Zancolli's series).¹¹ As a result of the muscle imbalance produced by the paralysis of the thumb extensors, and extensor carpi radialis brevis and longus, in relation to the unopposed activity of the extensor carpi ulnaris, the wrist develops an ulnar deviation. In general, strong action of the flexor carpi ulnaris, the extensor carpi ulnaris, or extensor digitorum communis often cause a notable muscle imbalance, which results in an ulnar deviation. Ulnar deviation of the wrist can be treated with a brace,

wrist arthrodesis (if growth is complete), temporary wrist fusion using a Steinman pin (if growth is incomplete) or a tendon transfer (with correction of the supination contracture) (Fig. 3). Tendon transfers include transfer of the extensor carpi ulnaris or the flexor carpi ulnaris to the extensor carpi radialis longus, or transfer of extensor carpi ulnaris or extensor carpi radialis longus to the abductor pollicis longus. For the former, the extensor carpi ulnaris is passed in palmar direction through the released interosseous membrane to the palmar aspect of the radius and sutured to the extensor carpi radialis longus (deep to the radial neurovascular bundle) under tension in 20 degrees wrist dorsiflexion.

RADIAL HEAD DISLOCATION

In patients with a volar dislocation, a long sling from the distal biceps tendon or triceps tendon can be elevated and wrapped around the radial neck, pulling it posteriorly. The sling can then be fixed under tension to the posterior aspect of the distal triceps and immobilized temporarily with a k-wire fixed from the radius to the ulna. In dorsal dislocations, a wedge osteotomy on the ulnar side of the radius is effective in reducing the radial head to a normal position.

HAND DEFORMITIES

The clinical presentation of the hand is highly variable. In general, any muscles available to restore hand function are very weak, leaving only one or two wrist motors available for transfer procedures. The hand frequently is faced with a disabling deformity where the thumb lies in an ulnarly deviated hand. If wrist extension is satisfactory, the extensor carpi ulnaris can be transferred to the abductor pollicis longus. If wrist extension is inadequate, the extensor carpi ulnaris can be transferred to the extensor carpi radialis brevis.

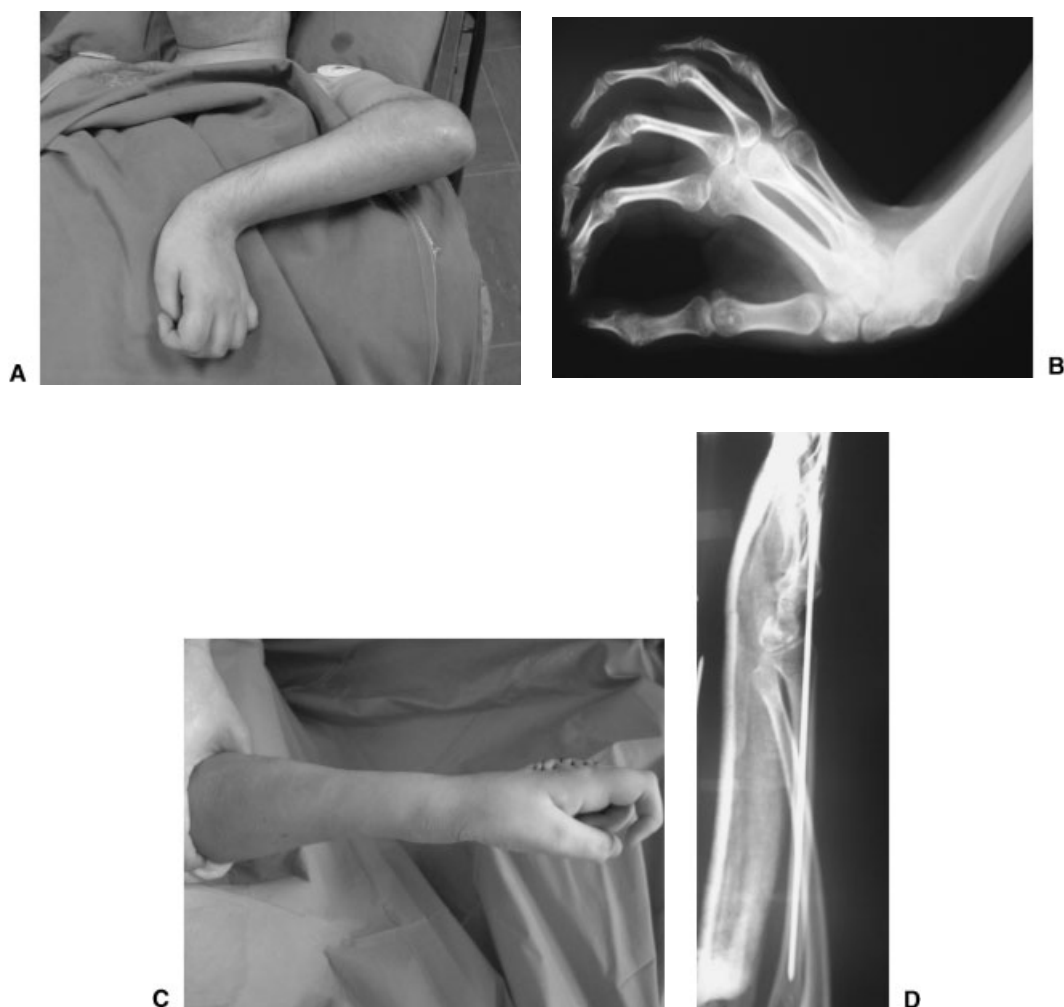


Figure 3 Temporary wrist fusion using a Steinman pin can be successfully used to correct ulnar deviation of the wrist if growth is incomplete. (A) Preoperative picture and (B) radiograph showing ulnar deviation and wrist hyperextension in a 14-year-old boy. (C,D) Postoperative views showing temporary fusion of the wrist using a Steinman pin from the shaft of the radius to the head of the second metacarpal.

METACARPOPHALANGEAL JOINT DROP AND WRIST DROP

Most OBPP patients show moderate wrist extension, but because of a weak extensor digitorum communis along with a weak extensor pollicis longus or abductor pollicis longus, they present with metacarpophalangeal joint drop. When the forearm flexors have retained adequate strength, a flexor to extensor transfer (such as that used for radial nerve palsy) is an appropriate means of treatment.^{30,31}

Tendon transfers that should also take into account the type of wrist deviation should be performed after careful assessment of the volar muscles of the forearm. Patients with weak wrist extension and ulnar deviation can be managed with a flexor carpi ulnaris to extensor carpi radialis longus transfer after stabilization of the wrist with wrist fusion. (Fig. 4) By passing the tendon around the radius, rather than through the interosseous membrane, both the wrist extension and

ulnar deviation of the wrist can be corrected. Thumb abduction and ulnar deviation of the wrist can be corrected by transfer of the flexor carpi ulnaris to the abductor pollicis longus.



Figure 4 Lateral view of wrist fusion using plate and screws, performed on a 16-year-old boy.

When the forearm flexors are weak, metacarpophalangeal joint drop can be corrected by using the musculocutaneous nerve as a transformator (neurotization source), by transferring the extensor carpi radialis longus to the extensor digitorum communis, by plication of the extensor digitorum communis or abductor pollicis longus, or by wrist fusion.

To use the musculocutaneous nerve as a transformator, the nerve is first isolated between the biceps and coracobrachialis muscles and then cut at its distal third. The distal end is directly coapted to the deep central branch of the three intercostal nerves,¹² and the proximal end is used to innervate the extensor digitorum communis muscle replacement (usually a gracilis myocutaneous functioning free muscle transplant). The proximal end of the muscle transplant is fixed to the proximal third of the humerus, and the distal end is sutured to the extensor digitorum communis.

In Klumpke palsy, wrist flexion and extension is usually only achieved by the flexor carpi radialis and extensor carpi radialis longus, respectively. By transferring the extensor carpi radialis longus to the extensor digitorum communis, one muscle can effectively do two functions. The four tendons of the extensor digitorum communis are moved superficial to the dorsal carpal ligament and sutured together. The extensor carpi radialis longus insertion can then be detached and sutured to the extensor digitorum communis.

FINGER FLEXION

Weak or partially absent finger flexion is often observed in total plexus palsy (Klumpke palsy). Extensor to flexor transfers in a manner similar to that performed for ulnar nerve palsy are effective for correcting finger flexion when good wrist extensor function is present.³² If strong wrist extensors are not available (which is usually the case), functioning free muscle transplantation for flexor digitorum profundus replacement is effective. This can be achieved using the intercostals as donor nerves or contralateral C7 transfer followed by two-stage free muscle transplantation. Recently, some authors recommended the use of the latissimus dorsi muscle for restoration of digital flexion.^{33,34} They have found that the thoracodorsal artery is sufficient for adequate nourishment of the entire length of the muscle, which is long enough to reach the wrist and be sutured to the flexor or extensor tendons of the fingers. Contraction of the latissimus dorsi transplant is sufficient for generating the complete range of digital movement. To obtain optimal results, antagonist muscles must also function properly. When there is paralysis of both flexion and extension of the digits, the latissimus dorsi muscle can be transferred for digital flexion, and the gracilis muscle for extension.^{33,34}

INTERPHALANGEAL JOINT EXTENSION

Intrinsic palsy of the hand can be managed using distal advancement of the central limb of the extensor mechanism to the base of the middle phalanx, by reconstruction of the lumbricales (achieved by flexor digitorum sublimis or extensor carpi radialis longus transfer), or by using an interphalangeal extension dynamic splint. Advancement of the extensor mechanism is indicated only in patients with positive metacarpophalangeal joint extension, who also have deficits in proximal interphalangeal joint extension. Correction is achieved by distal advancement of the central extensor mechanisms to the base of the middle phalanx in a manner similar to that performed for Boutonniere deformities.

REFERENCES

1. Erb WH. Über eine eigentümliche lokalisation von lahmen in plexusbrachialis. *Verhandl Naturhist Med Vereins* 1874;2:130-136
2. al-Qattan MM, Clarke HM, Curtis CG. The prognostic value of concurrent clavicular fractures in newborns with obstetric brachial plexus palsy. *J Hand Surg [Br]* 1994;19:729-730
3. Klumpke A. Contribution à l'étude des paralysies radicales du plexus brachial. *Rev Méd (Paris)* 1885;5:591-616
4. Terzis JK, Liberson WT, Levine R. Obstetric brachial plexus palsy. *Hand Clin* 1986;2:773-786
5. Narakas AO. Injuries to the brachial plexus. In: Bora FW Jr, ed. *The Pediatric Upper Extremity: Diagnosis and Management*. Philadelphia: WB Saunders; 1986:247-258
6. Berger AC, Hierner R, Becker MH. Die frühzeitige mikrochirurgische revision des plexus brachialis bei geburts-traumatischen Lasionen. *Patientenauswahl und Ergebnisse. Orthopade* 1997;26:710-718
7. Kawabata H, Masada K, Tsuyuguchi Y, Kawai H, Ono K, Tada R. Early microsurgical reconstruction in birth palsy. *Clin Orthop* 1987;215:233-242
8. Alanen M, Ryöppy S, Varho T. Twenty-six early operations in brachial birth palsy. *Z Kinderchir* 1990;45:136-139
9. Birch R, Bonney G, Wynn-Parry CB. Birth lesions of the brachial plexus. In: Sedden H, ed. *Surgical Disorders of the Peripheral Nerves*. Edinburgh: Churchill Livingstone; 1998:209-233
10. Gilbert A, Tassin JL. Reparation chirurgicale du plexus brachial dans la paralysie obstetricale. *Chirurgie* 1984;110:70-75
11. Zancolli E, Zancolli E. Reconstructive surgery in brachial plexus sequelae. In: Gupta A, Kay SPJ, Scheker LR, eds. *The Growing Hand: Diagnosis and Management of the Upper Extremity in Children*. St. Louis, MO: Mosby; 2000:805-823
12. Chuang DCC. Palliative surgery: forearm and hand deformities. In: Gilbert A, ed. *Brachial Plexus Injuries*. Paris: Martin Dunitz; 2001:294-302
13. Zancolli EA. Paralytic supination contracture of the forearm. *J Bone Joint Surg Am* 1967;49:1275-1284
14. Zancolli EA, Zancolli ER. Palliative surgical procedures in sequelae of obstetrical palsy. *Hand Clin* 1988;4:643-669
15. Adler JB, Patterson RL Jr. Erb's palsy. Long time results of treatment in eighty-eight cases. *J Bone Joint Surg Am* 1967;49:1052-1064

16. Doi K. Obstetric and traumatic pediatric palsy. In: Peimer A, ed. *Surgery of the Hand and Upper Extremity*. New York: McGraw-Hill; 1996:1443–1463
17. Hoffer HM. Assessment and natural history of brachial plexus injury in children. In: Gelberman RH, ed. *Operative Nerve Repair and Reconstruction*. Philadelphia: JB Lippincott; 1991:1361–1368
18. Lamb DW. Tendon transfers for paralytic states. In: Barron JN, Saad MN, eds. *The Hand. Operative Plastic and Reconstructive Surgery*. Edinburgh: Churchill-Livingstone; 1980:1163–1177
19. Marshall RW, Williams DH, Birch R, Bonney G. Operations to restore elbow flexion after brachial plexus injuries. *J Bone Joint Surg Br* 1988;70:577–582
20. Aziz W, Singer RM, Wolff TW. Transfer of the trapezius for flail shoulder after brachial plexus injury. *J Bone Joint Surg Br* 1990;72:701–704
21. Brunelli GA, Vigasio A, Brunelli GR. Modified Steindler procedure for elbow flexion restoration. *J Hand Surg [Am]* 1995;20:743–746
22. Manktelow RT, McKee NH. Free muscle transplantation to provide active finger flexion. *J Hand Surg [Am]* 1978;3:416–426
23. Terzis JK, Sweet RC, Dykes RW, Williams HB. Recovery of function in free muscle transplants using microvascular anastomoses. *J Hand Surg [Am]* 1978;3(1):37–59
24. Terzis JK, Vekris MD, Soucacos PN. Outcomes of brachial plexus reconstruction in 204 patients with devastating paralysis. *Plast Reconstr Surg* 1999;104(5):1221–1240
25. Doi K. New reconstructive procedure for brachial plexus injury. *Clin Plast Surg* 1997;24:75–85
26. Berger A, Becker M. Brachial plexus surgery: our concept of the last twelve years. *Microsurgery* 1994;15:760–767
27. Gilbert A, Tassin JL. Obstetrical palsy: a clinical, pathologic and surgical review. In: Terzis JK, ed. *Microreconstruction of Nerve Injuries*. Philadelphia: WB Saunders; 1987:529–553
28. Owings R, Wickstrom J, Perry J, Nickel V. Biceps brachii rerouting in treatment of paralytic supination contracture of the forearm. *J Bone Joint Surg [Am]* 1971; 53:137–142
29. Muhlig RS, Blaauw G, Sloof ACJ, Kortleve JW, Tonino AJ. Conservative treatment of obstetrical brachial plexus palsy (OBPP) and rehabilitation. In: Gilbert A, ed. *Brachial Plexus Injuries*. Paris: Martin Dunitz; 2001:173–187
30. Green DP. Radial nerve palsy. In: Green D, ed. *Operative Hand Surgery*. 3rd ed. New York: Churchill-Livingstone; 1993:1401–1417
31. Wheeler DR. Reconstruction for radial nerve palsy. In: Peimer A, ed. *Surgery of the Hand and Upper Extremity*. New York: McGraw-Hill; 1996:1363–1379
32. Omer GE. Combined nerve palsies. In: Green D, ed. *Operative Hand Surgery*. 3rd ed. New York: Churchill-Livingstone; 1993:1401–1417
33. Gousheh J, Arab H, Gilbert A. The extended latissimus dorsi muscle island flap for flexion or extension of the fingers. *J Hand Surg [Br]* 2000;25:160–165
34. Gousheh J. Palliative surgery: the hand. In: Gilbert A, ed. *Brachial Plexus Injuries*. Paris: Martin Dunitz; 2001:131–136